CLAIMS

WHAT IS CLAIMED IS:

1. A method of detecting ventricular collapse in a patient having a blood pump implanted, the method comprising:

sampling a time-based system parameter of the blood pump;

analyzing the time-based system parameter; and

calculating a suction probability index that provides an indication of the imminence of ventricle collapse.

2. The method of claim 1, wherein sampling a time-based system parameter of the blood pump includes sampling the pump current.

3. The method of claim 1, wherein sampling a time-based system parameter of the blood pump includes sampling the pump speed.

4. The method of claim 1, wherein the implantable pump includes a flow sensing device providing an indication of the flow rate through the pump, and wherein sampling a time-based system parameter of the blood pump includes sampling the flow rate.

5. The method of claim 1, further comprising converting the sampled time-based parameter to a digital signal.

6. The method of claim 1, further comprising computing the spectral content of the sampled time-based signal.

7. The method of claim 6, further comprising applying the computed spectral content to a spectral analysis equation to calculate the suction probability index.

8. The method of claim 7, wherein analyzing the time-based system parameter includes computing the total distortion of the time-based system parameter waveform.

9. The method of claim 8, wherein computing the spectral content includes applying a Fourier Transform, and wherein the suction probability index is calculated according to

$$\text{suction probability index} = \frac{\left[\sqrt{\sum_{n=1}^{x}\left[A\left[f_{(n \cdot dF)}\right]\right]^2 - \left[A\left[f_1\right]\right]^2}\right]\cdot 100}{\left|A\left[f_1\right]\right|}$$

wherein n indicates the position of the spectral component in the array resulting from the Fourier Transform; x is the last position in the array; dF represents the frequency resolution/interval of the Fourier Transform in Hertz; and f_1 is the fundamental frequency, maximum (amplitude) spectral peak in the array.

10. The method of claim 7, wherein analyzing the time-based system parameter includes computing the harmonic distortion of the time-based system parameter waveform.

11. The method of claim 10, wherein computing the spectral content includes applying a Fourier Transform, and wherein the suction probability index is calculated according to

$$\text{suction probability index} = \frac{\left[\sqrt{\sum_{n=2}^{x}\left[A\left[f_n\right]\right]^2}\right]\cdot 100}{\left|A\left[f_1\right]\right|}$$

wherein n indicates the n^{th} harmonic in the array resulting from the Fourier Transform; x is the last position in the array; f_1 is the fundamental frequency, the maximum (amplitude) spectral peak in the FFT resultant array; and f_n represents integer multiples of the fundamental f_1 from $n=2$ (second harmonic) to x (x^{th} harmonic).

12. The method of claim 7, wherein analyzing the time-based system parameter includes computing the distortion of the time-based system parameter waveform below the fundamental frequency.

13. The method of claim 12, wherein computing the spectral content includes applying a Fourier Transform, and wherein the suction probability index is calculated according to:

$$\text{suction probability index} = \frac{\left[\sqrt{\sum_{n=1}^{n(f1)-1}\left[A\left[f_{(n\cdot dF)}\right]\right]^2}\right]\cdot 100}{\left|A\left[f_1\right]\right|}$$

wherein n indicates the position of the spectral component in the array resulting from the Fourier Transform; dF represents the frequency resolution of the Fourier Transform in Hertz; f_1 is the fundamental frequency, the maximum (amplitude) spectral peak in the Fourier Transform resultant array; and $n(f1)$ is the position of the fundamental frequency in the array.

14. The method of claim 7, wherein analyzing the time-based system parameter includes computing the distortion of the time-based system parameter waveform above the fundamental frequency.

15. The method of claim 14, wherein computing the spectral content includes applying a Fourier Transform, and wherein the suction probability index is calculated according to:

$$\text{suction probability index} = \frac{\left[\sqrt{\sum_{n=n(f1)+1}^{x}\left[A\left[f_{(n\cdot dF)}\right]\right]^2}\right]\cdot 100}{\left|A\left[f_1\right]\right|}$$

wherein n indicates the position of the spectral component in the array resulting from the Fourier Transform; x is the last position in the array; dF represents the frequency resolution/interval of the Fourier Transform in Hertz; f_1 is the fundamental frequency, the maximum (amplitude) spectral peak in the array; and $n(f1)$ is the position of the fundamental frequency in the array.

16. The method of claim 14, wherein computing the spectral content further includes computing the ratio of additive frequency contributions above the fundamental frequency to the additive frequency contributions below the fundamental frequency, and wherein the suction probability index is calculated according to:

$$\text{suction probability index} = \frac{\left[\sqrt{\sum_{n=n(f1)+1}^{x}\left[A\left[f_{(n\cdot dF)}\right]\right]^2}\right]\cdot 100}{\left[\sqrt{\sum_{n=1}^{n(f1)-1}\left[A\left[f_{(n\cdot dF)}\right]\right]^2}\right]}$$

wherein *n* indicates the position of the spectral component in the array resulting from the Fourier Transform; *x* is the last position in the array; *dF* represents the frequency resolution/interval of the Fourier Transform in Hertz; f_1 is the fundamental frequency, the maximum (amplitude) spectral peak in the array; and *n(f1)* is the position of the fundamental frequency in the array.

17. The method of claim 7, wherein analyzing the time-based system parameter includes computing the distortion of the time-based system parameter waveform above a predetermined physiologic frequency.

18. The method of claim 17, wherein computing the spectral content includes applying a Fourier Transform, and wherein the suction probability index is calculated according to:

$$\text{suction probability index} = \frac{\left[\sqrt{\sum_{n=n(f_h)+1}^{x}\left[A\left[f_{(n\cdot dF)}\right]\right]^2}\right]\cdot 100}{\left|A\left[f_1\right]\right|}$$

wherein f_h is a spectral peak at the predetermined physiologic frequency; *n* indicates the position of the spectral component in the array resulting from the Fourier Transform; *x* is the last position in the array; *dF* represents the frequency resolution/interval of the Fourier Transform in Hertz; f_1 is the fundamental frequency, the maximum (amplitude) spectral peak in the resultant array

19. The method of claim 7, wherein analyzing the time-based system parameter includes computing the spread of the time-based system parameter waveform.

20. The method of claim 19, wherein computing the spectral content includes applying a Fourier Transform, and wherein the suction probability index is calculated according to:

$$\text{suction probability index} = \frac{\sqrt{\sum_{n=1}^{N} \left[A\left[f_{(n \cdot dF)}\right] - A\left[f_1\right]\right]^2}}{N}$$

wherein f_1 is the maximum (amplitude) spectral peak in the array resulting from the Fourier Transform; dF represents the frequency resolution/interval of the Fourier Transform in Hertz; n indicates the position of the spectral component in the array; and N is the last position in the array.

21. The method of claim 6, further comprising comparing the computed spectral content to a predetermined spectral mask to calculate the suction probability index.

22. The method of claim 19, wherein computing the spectral content includes applying a Fourier Transform.

23. The method of claim 19, wherein computing the spectral content includes applying the sampled time-based signal to a synchronous switched-capacitor filter.

24. The method of claim 1, wherein analyzing the time-based system parameter includes calculating the slope of the time-based system parameter.

25. The method of claim 24, wherein calculating the suction probability index includes comparing the slope to a predetermined value.

26. The method of claim 24, wherein calculating the slope includes calculating the first derivative of the time-based parameter.

27. The method of claim 24, wherein calculating the slope includes calculating the second derivative of the time-based parameter.

28. A control system for an pump system, the control system comprising:

a processor having inputs for receiving a signal representing a time-based parameter of the pump system;

the processor being programmed to analyze the time-based system parameter and calculate a suction probability index that provides an indication of the imminence of ventricle collapse.

29. The control system of claim 28, wherein the time-based parameter includes the pump system current.

30. The control system of claim 28, wherein the time-based parameter includes the pump system flow rate.

31. An pump system, comprising:

an pump including a motor having a rotor and a stator, the stator including a plurality of stator windings;

a motor controller coupled to the motor;

a processor having inputs coupled to the motor controller for receiving a signal representing a time-based parameter of the pump;

the processor being programmed to analyze the time-based system parameter and calculate a suction probability index that provides an indication of the imminence of ventricle collapse.

32. The pump system of claim 31, wherein the motor controller applies current to the stator windings in a sequence to create a rotating field; and wherein the time-based parameter includes the stator winding current.

33. The pump system of claim 31, further comprising an implantable flow sensing device coupled to the processor for providing a signal representing the pump flow rate, wherein the time-based parameter includes the pump flow rate.

34. An pump system, comprising:

an pump including a motor having a rotor and a stator, the stator including a plurality of stator windings;

a motor controller coupled to the motor;

means coupled to the motor controller for analyzing a time-based parameter of the pump calculating a suction probability index that provides an indication of the imminence of ventricle collapse.